

METHOD OF SELECTIVELY MAKING COPPER USING PLATING TECHNOLOGY

FIELD OF THE INVENTION

The invention relates to a method of fabricating a copper interconnect with improved performance and in particular to a method of forming an electroconductive layer that serves as a hard mask during an etch transfer step and as a stop layer during a chemical mechanical polish step.

BACKGROUND OF THE INVENTION

The manufacture of integrated circuits in a semiconductor device involves the formation of a sequence of layers that contain metal wiring. Metal wiring that forms interlevel and intralevel connections in a device is insulated by one or more dielectric layers in order to prevent crosstalk between the electrical pathways which can degrade device performance. A popular method of forming metal wiring is a damascene process in which a metal is deposited in an opening such as a via hole or a trench above a via in a dielectric layer. Usually, a conformal diffusion barrier layer is formed between the metal layer and dielectric layer to protect the metal from corrosion and oxidation and to prevent metal ions from migrating into the dielectric layer. The metal layer is typically planarized by a chemical mechanical polish (CMP) process.

Recent progress in forming metal interconnects includes lowering the resistivity of the metal by replacing aluminum with copper, decreasing the width of the vias and trenches with improved lithographic materials and processes to

improve speed and performance, and reducing the dielectric constant (k) of insulating materials to minimize capacitance coupling between the metal interconnects. Current technology involves forming vias and trenches that have sub-micron dimensions which are generally below 0.30 microns. Some leading edge devices have critical dimensions that are 100 nm or less. Although SiO_2 which has a dielectric constant of about 4 has been widely used as a dielectric layer in older technologies, dielectric materials with a k value of less than about 3 are being implemented in new devices.

It should be noted that as the width of via holes or trench openings is shrinking in new technologies, the difficulty in forming a uniform thin diffusion barrier layer has resulted in adopting new techniques that include atomic layer deposition (ALD). For small holes, ALD is often preferred over chemical vapor deposition (CVD) methods for its improved gap filling capability and flexibility in composition by enabling a composite layer with three or more elements to be deposited in variety of monolayer sequences.

A recent advance in copper deposition as described in U.S. Patent 6,420,258 involves a selective growth of copper by an electrochemical method on a conformal seed layer in a trench. The method reduces non-uniformity in metal CMP and thereby minimizes dishing at the top of the copper interconnect. However, a first CMP step that is used to remove the seed layer on the surface of the substrate can be difficult to control since the underlying diffusion barrier layer is frequently too thin to function as a good CMP stop.

A diffusion barrier cap is selectively deposited on a metal interconnect in U.S. Patent 6,153,935 and provides corrosion protection and improved electromigration resistance. A barrier layer which is rhenium, rhodium, or ruthenium is formed on a copper interconnect in U.S. Patent 6,441,492 and affords high resistance to Cu diffusion.

Dishing on a copper layer during a CMP step is avoided in U.S. Patent 6,004,188 by employing a Ti/TiN sacrificial barrier layer on a dielectric layer, forming an opening in the dielectric layer, and depositing a Ta/TaN diffusion barrier liner in the opening prior to depositing a Cu layer. The copper level is lowered during a first CMP step that also removes the Ta/TaN above the dielectric layer at a relatively slow rate. Then a second CMP step planarizes the Cu while removing Ti/TiN at a similar rate. A sacrificial layer is also used in U.S. Patent 6,417,095 and eliminates the need for a CMP step.

In U.S. Patent 6,528,426, a SiC CMP stop layer is utilized to protect an underlying mechanically weak dielectric layer such as porous SiO₂. Conformal nitride and Ta barrier layers are formed on the sidewalls of a dielectric layer in U.S. Patent 6,509,267 to prevent Cu from being sputtered onto the dielectric layer during a via etch.

A carbon electroconductive layer is formed on the sidewalls and bottom of an opening in an amorphous C and F containing dielectric layer by a plasma treatment in U.S. Patent 6,482,741. The electroconductive layer functions as a diffusion barrier and as a seed growth layer for a copper layer. However, the method does not provide a means for preventing Cu dishing.

Therefore, an improved method of forming copper wiring is needed which involves a good stop layer during a first CMP step to remove a copper seed layer from selective portions of the substrate. The method should also prevent dishing during a second CMP step to planarize a copper interconnect layer that is formed in an opening within a dielectric layer by an electrochemical process. The method should also be compatible with incorporation of a diffusion barrier layer between the copper layer and the dielectric layer.

SUMMARY OF THE INVENTION

An objective of the present invention is to provide an improved method for fabricating copper wiring that affords good CMP uniformity during planarization of a copper interconnect layer.

A further objective of the present invention is to provide an improved method of forming copper wiring that involves an electrochemical deposition and which prevents a CMP step used to polish a copper seed layer from punching through a diffusion barrier layer into a dielectric layer.

A still further objective of the present invention is to provide an electroconductive layer that can serve as a hard mask and CMP stop layer in a damascene scheme.

These objectives are achieved by incorporating an electroconductive layer in a damascene scheme. A substrate is provided that typically has a first metal layer with an exposed upper surface. An etch stop layer and dielectric layer are sequentially formed on the substrate. An electroconductive layer is deposited by

a chemical vapor deposition (CVD), plasma enhanced CVD, or physical vapor deposition (PVD) "sputtering" method on the dielectric layer and will serve as a hard mask during a subsequent plasma etch process. A photoresist is coated and patterned to form an opening such as a trench or via hole on the electroconductive layer. Then the opening is transferred through the underlying layers with a plasma etch process and exposes a portion of the first metal layer. Alternatively, the opening may be a trench formed above a via hole in a dual damascene fabrication.

A conformal diffusion barrier layer is deposited on the electroconductive (EC) layer and on the sidewalls and bottom of the opening. Next, a copper seed layer is formed on the diffusion barrier layer and is removed above the EC layer by a first CMP step. The presence of the EC layer prevents the first CMP process from eroding the dielectric layer in situations where the thin diffusion layer is entirely removed above the dielectric layer. The EC layer functions as a stop layer since it preferably has a slower polish rate than the adjacent diffusion barrier layer and copper seed layer. A copper layer that will become an interconnect is selectively deposited by an electrochemical process on the remaining copper seed layer to fill the opening. A second CMP step is performed to lower the level of the copper layer until it is coplanar with the dielectric layer. In so doing, the EC layer and the diffusion barrier layer above the dielectric layer are removed and a copper interconnect is completed with good uniformity and improved performance.

In a second embodiment, the first CMP step is used to remove the copper seed layer and the diffusion barrier layer above the dielectric layer. The EC layer

on the top surface of the dielectric layer ensures that the entire surface of the substrate is electroconductive to enable a selective electrochemical copper deposition to occur in a subsequent step. A copper layer is formed on the remaining seed layer in the opening with a selective electrochemical deposition as described in the first embodiment. A second CMP step then planarizes the copper layer to form an interconnect and also removes the EC layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The object and other advantages of this invention are best described in the preferred embodiments with reference to the attached drawings that include:

FIGS. 1a – 1c which are cross-sectional views depicting a prior art method of planarizing a copper seed layer that is formed as part of a damascene structure.

FIGS. 2 – 7 which are cross-sectional views illustrating the formation of a copper interconnect by employing an electroconductive layer according to one embodiment of the present invention.

FIGS. 8 - 9 which are cross-sectional views showing the planarization of a copper seed layer during the formation of a copper interconnect according to a second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is particularly useful in forming metal wiring with improved uniformity and high performance in an integrated circuit that is part of a microelectronic device. Preferably, the metal is copper and the copper wiring

may be in the form of an interconnect that is fabricated by a single or dual damascene scheme. However, another metal or a metal alloy may be used to form an interconnect. A first embodiment is depicted in FIGS. 2 – 7. Although the figures depict a single damascene sequence, it should be understood that the invention is equally effective in a dual damascene method that involves a via first approach where a trench is formed above a via. Furthermore, the figures are not necessarily drawn to scale and are not intended to limit the scope of the invention.

As a background to the present invention, the inventors have previously practiced a copper wiring method as represented in FIGS. 1a – 1c. Referring to FIG. 1a, a substrate **10** is provided that is typically silicon and which contains a conductive layer **11** with an exposed surface. There may be other conductive and dielectric layers in substrate **10** that are not shown in order to simplify the drawing.

A dielectric layer **12** is formed on substrate **10** by a CVD, PECVD, or spin-on method. Next, an opening **13** such as a trench or via is formed in dielectric layer **12** by a conventional method. A diffusion barrier layer **14** comprised of TaN, Ti/TiN, TiN, or WN is deposited with a PVD process followed by deposition of a copper seed **15** layer using a PVD technique.

Referring to FIG. 1b, a first CMP step is employed to remove the copper seed layer **15** above dielectric layer **12**. A continuous diffusion barrier layer **14** remains in order to enable a subsequent selective copper electrochemical deposition to proceed. Since the diffusion barrier layer **14** may be as thin as 100 Angstroms,

the polish step may remove barrier layer **14** in some regions of substrate **10** and begin to thin dielectric layer **12**. This action can produce scratches on dielectric layer **12** which can lead to a loss in device performance. Moreover, dielectric layer **12** can become thinner in some regions of the substrate than in others because of some non-uniformity in the CMP process. The resulting lack of planarity will cause a subsequent copper deposition process to form copper wiring with variable thickness in the non-planar dielectric layer **12** which in turn will have a deleterious effect on device performance. For example, copper sheet resistance (R_s) is proportional to the cross-sectional area of a copper line. Therefore, copper R_s will vary across a substrate when dielectric layer **12** is not planar.

In FIG. 1c, a copper layer **16** is deposited on copper seed layer **15** in opening **13** by a selective electrochemical process. A second CMP step is used to remove diffusion barrier layer **14** above dielectric layer **12** and lower the level of copper layer **16** to be coplanar with dielectric layer **12**. When dielectric layer **12** in the vicinity of opening **13** is thinner than desired by over polishing during the first CMP step, the resulting copper layer **16** in opening **13** will have a thickness below a specified limit. Therefore, a method which provides better thickness control of dielectric layer **12** during planarization of copper seed layer **15** is necessary.

The inventors have discovered that an electroconductive (EC) layer when incorporated into a copper wiring fabrication sequence provides a method of controlling a subsequent planarization step of a copper seed layer and thereby improves copper wiring uniformity and device performance. In its simplest form,

the present invention involves filling an opening in a dielectric layer on a substrate with a uniform metal layer. The preferred embodiments are described according to a damascene scheme. A first embodiment is shown in FIGS. 2 – 7.

Referring to FIG. 2, a substrate **20** is provided that is typically silicon but may be based on silicon-on-insulator, silicon germanium, or gallium-arsenide technology. Substrate **20** has a conductive layer **21** with an exposed surface that may be enclosed on the sides and bottom by a diffusion barrier layer (not shown) in order to prevent corrosion and oxidation of conductive layer **21**. Substrate **20** may be comprised of insulating layers and other conductive layers which are not shown in order to simplify the drawing.

An etch stop layer **22** that is comprised of silicon nitride, silicon oxynitride, or silicon carbide is deposited on substrate **20** by a CVD or PECVD process. A dielectric layer **23** having a thickness of from 1000 to 10000 Angstroms is then formed by a CVD, PECVD, or spin-on technique. The dielectric layer **23** is SiO₂ or preferably is a low dielectric constant (k) material with a k value of less than about 3.5 and more preferably, k is less than 3. Examples of a low k material that may be used in dielectric layer **23** are fluorine doped SiO₂ (fluorosilicate glass), carbon doped SiO₂, nitrogen doped SiO₂, polysilsesquioxanes such as HSQ and MSQ, polyarylethers, benzocyclobutene (BCB), borophosphosilicate glass, and fluorinated polyimides. Dielectric layer **23** may be annealed at temperatures of up to 600°C to remove trace amounts of water and other impurities. Furthermore, the dielectric layer **23** may be subjected to a plasma treatment known to those

skilled in the art to densify the layer and thereby stabilize a low k dielectric constant and prevent water uptake.

A key feature of this invention is the deposition of an EC layer **24** having a thickness in the range of about 50 to 2000 Angstroms and preferably 50 to 1000 Angstroms on dielectric layer **23** by a PVD or CVD process. EC layer **24** is selected from a group of materials including W, Al, WN, Ti, and TiN. Alternatively, EC layer **24** may be a metal compound, metal alloy, or an amorphous metal that is a good electrical conductor and which can function as a stop layer in a copper CMP process and as a hard mask during a pattern transfer with an oxygen based plasma etch.

A photoresist layer **25** is coated on EC layer **24** and is patterned by conventional means using an exposure tool and one or more exposure wavelengths from about 10 to 600 nm to form an opening **26** that is aligned above conductive layer **21**. Alternatively, the exposure tool is a projection electron beam tool. Opening **26** may be a via hole or trench and preferably has a width that is about 200 nm or less and may be 100 nm or less in newer technology devices. Note that while FIG. 2 shows one opening **26** in photoresist layer **25** above one conductive layer **21**, other designs are possible including the formation of more than one opening over a conductive layer **21**.

Referring to FIG. 3, the opening **26** is transferred through EC layer **24**, dielectric layer **23**, and etch stop **22** by one or more plasma etch steps that are known to those skilled in the art. Photoresist layer **25** may be totally consumed by the transfer step through dielectric layer **23** or during the etch through etch

stop **22**. In situations where photoresist layer **25** is consumed before conductive layer **21** is exposed at the bottom of opening **26**, EC layer **24** functions as a hard mask to protect underlying dielectric layer **23**. A hard mask capability in EC layer **24** is especially valuable when dielectric layer **23** has an organic (C, H) component that is susceptible to an oxygen containing plasma etch. Therefore, EC layer **24** should have a low etch rate in an oxygen based plasma and metal oxides formed during the plasma etch are preferably volatile to avoid undesirable residues. A standard wet clean process may be used to remove organic residues following the plasma etch transfer of opening **26** to expose conductive layer **21**.

Referring to FIG. 4, a diffusion barrier layer **27** that is preferably conformal and having a thickness of about 20 to 500 Angstroms is deposited on EC layer **24** and on the sidewalls and bottom of opening **26**. In one embodiment, diffusion barrier layer **27** is comprised of Ta, TaN, Ti, TiN, TiSiN, TaSiN, W, WN, or an amorphous metal and is deposited with a CVD, PECVD, physical vapor deposition (PVD) or atomic layer deposition (ALD) method.

Note that while EC layer **24** and diffusion barrier layer **27** may contain the same material, the two layers are typically different materials since the diffusion barrier layer is selected for good adhesion to copper and as a barrier to copper ions while an EC layer is chosen for adhesion to an underlying dielectric layer, to provide good etch resistance during the pattern transfer process, and for its relatively low polish rate during copper CMP. In an exemplary process, W may be preferred as an EC layer while Ta or TaN is selected as the diffusion barrier layer.

A copper seed layer **28** is then deposited on diffusion barrier **27** by a PVD, PECVD, or ALD method, depending on the width of the opening **26**. Copper seed layer **28** is also a conformal coating and has a thickness of about 10 to 1000 Angstroms. As a result, an opening **26a** is formed inside the original opening **26**.

The first embodiment is continued in FIG. 5 by employing a planarization method such as a first CMP process, for example, to remove copper seed layer **28** above EC layer **24**. Conditions for performing the first CMP process are well known to those who practice the art and are not described herein. Note that the thin diffusion barrier metal layer **27** is also removed above EC layer **24** in this embodiment. In this case, the EC layer **24** is selected because it is a good CMP stop and preferably has a polishing rate that is less than the polishing rate for diffusion barrier layer **27**. Copper is relatively soft and Cu seed layer **28** has a polish rate that is usually higher than the removal rate of diffusion barrier layer **27**. EC layer **24** may be thinned somewhat during the first CMP process but its polish rate is low enough to ensure a continuous coverage of dielectric layer **23**. The top surfaces of diffusion barrier layer **27** and copper seed layer **28** within opening **26** are now coplanar with EC layer **24**.

Referring to FIG. 6, a selective electrochemical deposition similar to the method described in U.S. Patent 6,420,258 is performed to grow a copper layer **29** on copper seed layer **28** and provide a good Cu seal in opening **26a**. Copper layer **29** forms only on copper seed layer **28** and fills opening **26a**. Although copper layer **29** is shown as a distinct layer on copper seed layer **28** for illustrative purposes, copper layer **29** and copper seed layer **28** are typically not

distinguishable from one another. Note that copper layer **29** extends slightly above the top surface of diffusion barrier layer **27**.

Referring to FIG. 7, a copper interconnect comprised of copper layer **29** and copper seed layer **28** is completed by a planarization step. For example, a second CMP process similar to the first CMP process is used to planarize copper layer **29** to be coplanar with dielectric layer **23**. The second CMP process also removes EC layer **24** and the top portions of diffusion barrier layer **27** and copper seed layer **28** in opening **26**. Since only a thin portion of copper layer **29** is removed, the second CMP process is capable of planarizing the copper layer with little or no dishing.

The copper interconnect comprised of copper layer **29** and copper seed layer **28** in opening **26** and other copper interconnects (not shown) that are fabricated in other openings within dielectric layer **23** are more uniformly formed than in prior art because EC layer **24** controls the first CMP process to afford a more uniform height of a copper seed layer within the aforementioned openings. Copper layer **29** and other copper wiring in dielectric layer **23** is fabricated at a more uniform height than previously achieved which thereby affords a more uniform copper sheet resistance (R_s) across the substrate **20** and imparts a higher performance to the microelectronic device. In addition, a conventional CMP step that removes a continuous thick copper layer above dielectric layer **23** on substrate **20** is eliminated in the present invention. The two CMP steps in the present invention require less consumables than a conventional CMP process and are considered a cost savings measure. The method of the present invention

provides an advantage in that the two CMP steps are more highly controlled than a conventional CMP step and thereby afford a device with less dishing in the copper layer and higher reliability.

A second embodiment is shown in FIGS. 2 - 4 and FIGS. 7 - 9 and provides an alternative approach in utilizing an EC layer during the fabrication of a copper interconnect. A description of FIGS. 2 - 4 was given previously in the first embodiment wherein an opening **26** is formed in a stack of layers comprised of an upper EC layer **24**, a middle dielectric layer **23**, and a lower etch stop layer **22** on a substrate **20**. EC layer **24** can serve as a hard mask during the etch transfer of opening **26** through the stack of exposed layers **22**, **23**, **24** to protect an underlying dielectric layer **23** comprised of organic (C,H) components. Opening **26** is aligned above a conductive layer **21** in substrate **20**. A conformal diffusion barrier layer **27** is formed in opening **26** and on EC layer **24** followed by deposition of a conformal copper seed layer **28** on diffusion barrier layer **27** as mentioned in the first embodiment. A smaller opening **26a** is now located within the original opening **26**.

Referring to FIG. 8, a first planarization step that is a CMP process, for example, is performed to remove the copper seed layer **28** above EC layer **24**. The CMP process stops on diffusion barrier layer **27**. In some regions of the substrate, the CMP step may break through the thin diffusion barrier layer **27** because of some nonuniformity in the polishing process. In this case, EC layer **24** serves as a stop layer to prevent the CMP step from penetrating into the

dielectric layer **23** and causing scratches or dishing that can detract from device performance.

Referring to FIG. 9, a selective electrochemical deposition similar to the method described in U.S. Patent 6,420,258 is performed to grow a copper layer **29** on copper seed layer **28** and provide a good Cu seal in opening **26**. Copper layer **29** forms only on copper seed layer **28** and fills opening **26a**. Note that copper layer **29** extends slightly above the surface of diffusion barrier layer **27**.

Returning to FIG. 7, a copper interconnect comprised of copper layer **29** and copper seed layer **28** is completed by a second planarization process. For example, a second CMP step similar to the first CMP step is used to lower the level of copper layer **29** to be coplanar with dielectric layer **23**. The second CMP step also removes EC layer **24** and diffusion barrier layer **27** above dielectric layer **23** and removes a top portion of copper seed layer **28**. Since only a thin portion of copper layer **29** is removed, the amount of dishing is substantially reduced compared to a conventional CMP step where a continuous thick copper layer must be thinned.

The copper interconnect comprising copper layer **29** and copper seed layer **28** in opening **26** and other copper interconnects (not shown) that are fabricated in other openings within dielectric layer **23** are more uniformly formed than in prior art because EC layer **24** helps to control the first CMP step to afford a more uniform height of a copper seed layer within the aforementioned openings and a more uniform thickness of dielectric layer **23** across the substrate **20**. Copper layer **29** and other copper wiring in dielectric layer **23** is fabricated at a more

uniform height than previously achieved which results in a more uniform copper sheet resistance across substrate **20** and a higher performance to the microelectronic device.

While this invention has been particularly shown and described with reference to, the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of this invention. For instance, the method of the first or second embodiment may be performed more than once on a substrate to build a multilevel copper interconnect structure in which a copper layer on one level is electrically connected to one or more underlying copper layers.